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Fault diagnosis of induction motor using wavelets

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***Abstract*— Wavelet analysis is one the prime signal processing and data analysis techniques its ability to locate fault at exact duration is one of its added advantage in comparison to Fast Fourier transform in which time information of signal is lost .In addition to this FFT has another disadvantage i.e. at low loads sidebands converges so it becomes difficult to detect the faults. STFT was proposed as a solution to resolution problem but it has limited time-frequency resolution capability, because of the uncertainty principle Low frequencies can be scarcely depicted with short window that's why wavelet theory is yet the most powerful tool in data analysis of signals. This paper presents a study of fault detection of induction motor like broken rotor bars ,stator short circuits using wavelets envelope analysis in which a signal is converted into approximate and detail signals thus removing the fundamental current which hides the fault harmonics present during faults.**

Keywords— ***wavelet analysis, induction motor, fast Fourier transform***

I. Introduction

Real world data or signals exhibits frequently oscillating change disturbed with transients ,most of the time abrupt changes in the signal are our primary concern in data analysis. The Fourier transform is one of the powerful tool for data analysis but it fails to represent abrupt changes efficiently the reason for this is the Fourier transforms represents data into a sum of sine waves which are not localized in time and space also these sine waves keeps on oscillating without giving any idea about abrupt changes .Unlike sinusoids a wavelet exists for a finite duration, a wavelet is a rapidly decaying wave like oscillation that has zero mean, wavelets come in different sizes and shape and these wide variety of mother wavelet functions is a key strength in wavelet analysis. In this paper basic of DWT is taken into consideration after that the need of wavelets in condition monitoring scenario of induction motor is approached. There after the decomposition of signal into approximate and details signals is explained the proper choice of sampling frequency is crucial for detection of faults using [illegible] upper sidebands frequency from the principal frequency component. Using a Matlab setup broken rotor bar fault and stator winding short circuit fault is induced in the simulation and thus faults can be detected using wavelet analysis by observing the change in energy of the decomposed signals.

II. DWT (discrete wavelets transform)

Wavelet techniques are new in the field of fault diagnosis. They are useful due to their ability to extract all the information in both time and frequency domain. It gives an efficient way to diagnose the faults in comparison to other signal processing methods like the Fourier Transform, the drawbacks of which include the need to employ a single window function in all frequency components and the acquisition of linear resolution in the whole frequency domain. Multi resolution analysis and good time localization are particularly useful characteristics of wavelets in the context of fault diagnosis Signal processing techniques like the FFT are based on the assumptions of constant stator fundamental frequency, load, and motor speed and that the load should be sufficient.

Fig 1 A Morlet wavelet

The wavelet is divided into two main groups. One is the discrete wavelet transform represented in the following Eq 1

$$DWT(m,k) = \frac{1}{\sqrt{a_0^m}} \sum x(n) g(\frac{k - nb_0 a_0^m}{a_0^m}) \quad (1)$$

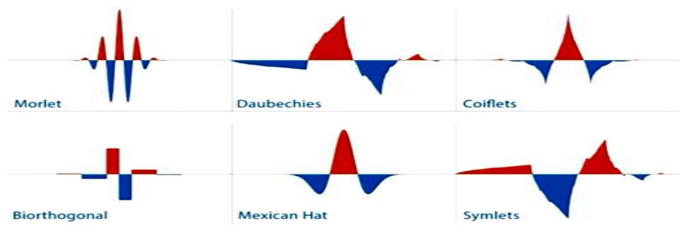

Fig 2 various types of wavelets

Where $g(n)$ is the mother wavelet $x(n)$ is the input signal and the scaling and translation parameters " a "and " b " are [illegible] m ,for a wavelet there is a reciprocal relation between scale and wavelets .Scaling a wavelet simply means compressing.

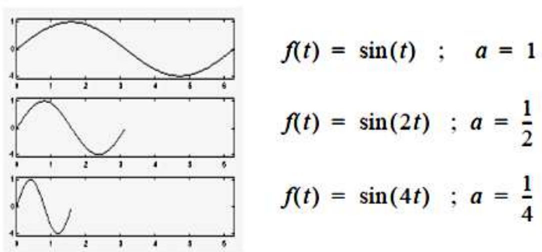

Fig 3 scaling of a sinusoid

The scale factor works exactly the same with wavelets. The smaller the scale factor, the more "compressed" the wavelet.

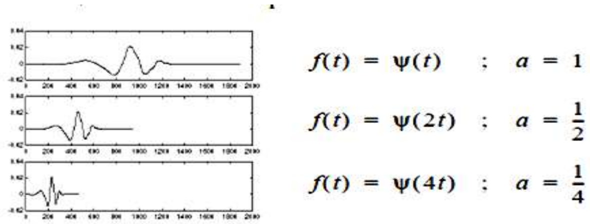

Fig 4 Scaling of a wavelet

The second wavelet type is the continuous wavelet transform (CWT) [1]which can be represented as follows :

$$\omega(m,n) = \int_{-\infty}^{+\infty} f(t)\psi^*_{m,n}(t)dt \tag{2}$$

* denotes the complex conjugate, where f (t) is the waveform signal and Ψ(t) is a wavelet. The key applications of CWT are time frequency analysis, and filtering time localized frequency components and that of DWT are de noising and compression of signal and images.

III. Fault detection using wavelets

Many Electric drives are used in safety application and thus its unexpected breakdown is not acceptable. Fault detection depends on the availability of information from the system. In this work, the fault detection is done using wavelet for analysis of stator current. The use of Motor Current Signature Analysis (MCSA) of stator current using wavelet to perceive the fault in a broken rotor bar in the transient region was done by [2].

[3] Demonstrated a practical technique of obtaining the wavelet decomposition by convolution of the signal with a low-pass and high-pass filters followed by a down sampling by 2. Fig. 4 illustrates this procedure where h[n] and g[n] are the impulse responses of the filters and the results are called approximation and detail coefficients respectively.

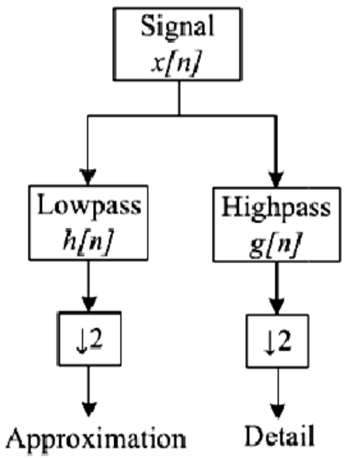

Fig 5 Wavelet Decomposition

The approximations are the high-scale, low-frequency components of the signal. The details are the low-scale, high-frequency components. As the original signal is passed through two complementary filters it emerges as two different signals. It creates a problem which is generating twice as much data as we started with. If the original signal S consists of 1000 samples of data. In that case the approximation and the detail signals will each have 1000 samples, which make a total of 2000. That is why down sampling is needed, which means throwing away every second data point.

The decomposition can be implemented using filtering and down-sampling, and can be iterated, with successive approximation as in [4]. The total decomposition levels (L) can be calculated according to the following relationship:

$$L \geq \frac{\log\left(\frac{f_s}{f}\right)}{\log(2)} + 1 \tag{3}$$

At a sampling frequency of 3.264 kHz, a eight level decomposition occurs

$$L = \frac{\log\left(\frac{3264}{50}\right)}{\log(2)} + 1 = 8levels$$

Table 1. Frequency bands for the 8 levels of decomposition

Approx	Freq band	detail	Freq band
A8	0-12.75	D8	12.75-25.5
A7	0-25.5	D7	25.5-51
A6	0-51	D6	51-102
A5	0-102	D5	102-204
A4	0-204	D4	204-408
A3	0-408	D3	408-816
A2	0-816	D2	816-1632
A1	0-1632	D1	1632-3264

$$A[0 - 2^{-n}F_s] \tag{4}$$
$$D[2^{-n}F_s - 2^{-(n-1)}F_s] \tag{5}$$

Frequency band can be calculated through these equations.

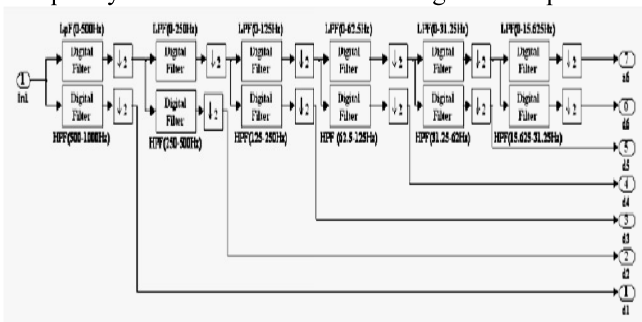

Fig. 5.Wavelet decomposition levels using FDA matlab tool box

Another way to performing this task is through the DWT dyadic filter from MATLAB/Simulink. Although for this method, the wavelet coefficients may need to be calculated using the following MATLAB instruction: [Lo_D, Hi_D, Lo_R, Hi_R] = wfilters('db10') .Where Lo_D, Hi_D, Lo_R, Hi_R represent low pass filter decomposition, high pass filter decomposition ,low pass filter reconstruction and high pass filter reconstruction respectively.

Among many possible reasons the prime reasons of broken rotor bar are [5] Direct on line starting which leads to excessive heating and symmetry in an induction motor which generates back ward rotating wave along with main magnetic field ,this backward wave induces stator voltage harmonic mechanical problems, pulsating load. Manufacturing or installing defects, environmental stress. Broken rotor bars disturbs electrical components at a particular frequency given by [6]

$$f_l[k] = f_1(1 - 2ks) \tag{6}$$
$$f_u[k] = f_1(1 + 2ks) \tag{7}$$

IV. Simulation results

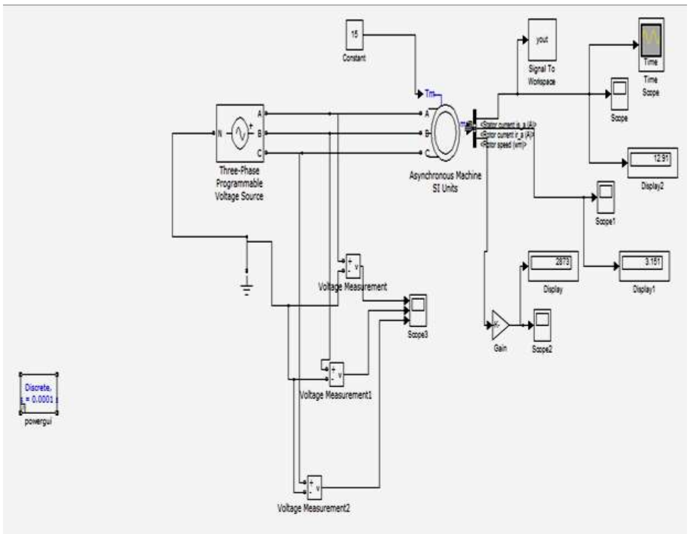

Fig 6 Matlab simulation setup

PARAMETERS

Table 2 Induction motor specifications

Motor specifications	Unit	value
Power	Watts	7500
Current	Ampere	12.9
voltage	Volt rms	400
speed	Rpm	2875
Pole pairs		1
Moment of inertia	Kg.m^2	0.0131
Stator resistance	Ohm	0.734
Stator inductance	Henry	0.003045
Rotor resistance	Ohm	1.5
Rotor inductance	Henry	0.003045

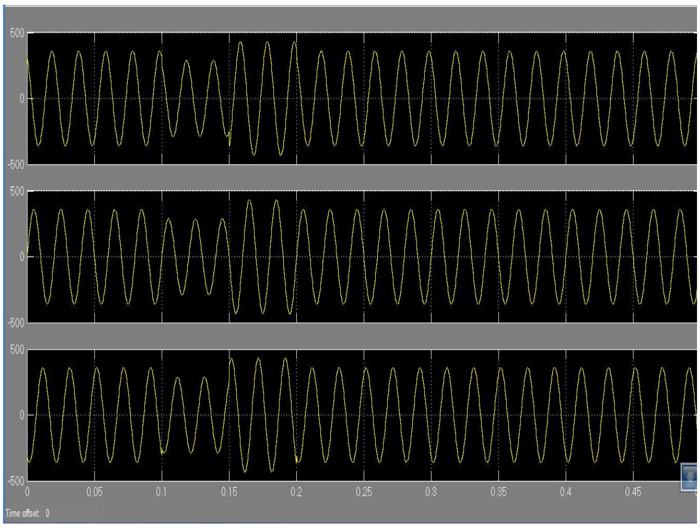

Fig 7 input voltages non stationary

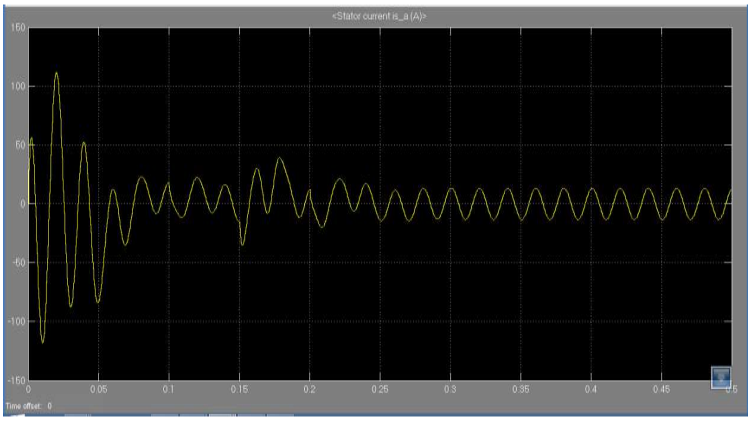

Fig 8 Stator current Is = 12.51A

After initial transients stator current settles down to 12.51 A .Non stationary input voltage ensures the proper use of wavelet analysis of the induction motor.

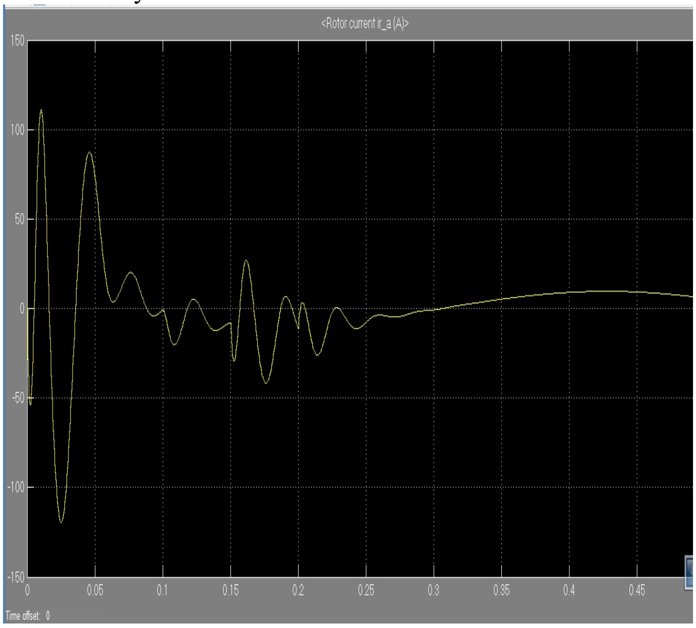

Fig 9 rotor current I_r = 5.806A

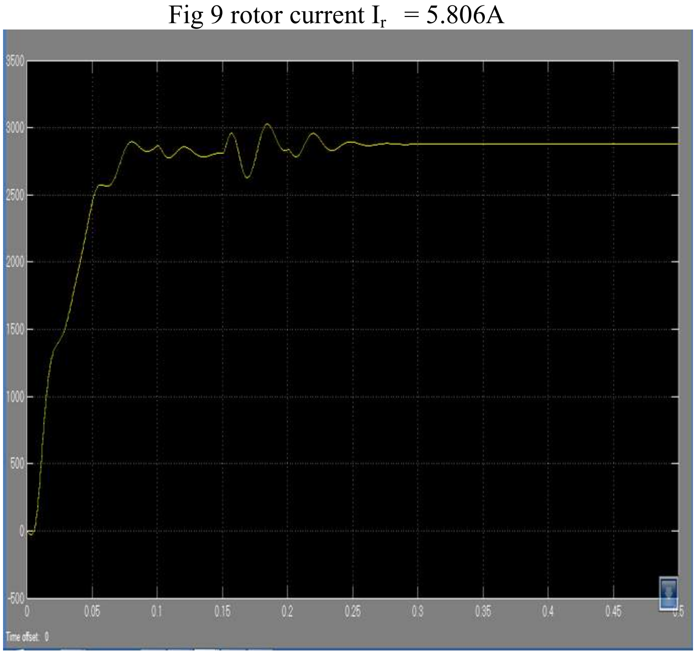

Fig 10 Speed 2877RPM

For simulation of broken rotor bars incremental resistance can be calculated with the help of these equations,

$$\Delta R = R_{br} - R_r \qquad (8)$$

$$= \frac{3R_{bar}}{N_b - n} - \frac{3R_{bar}}{N_b} = 3R_{bar}\left[\frac{1}{N_b - n} - \frac{1}{N_b}\right] \qquad (9)$$

By calculating incremental resistance through this formula this resistance is added with initial rotor resistance per phase to simulate broken bar fault.

Detection of sidebands by wavelet method

Sidebands can be detected by Detecting Discontinuities and Breakdown Points in wavelet signal. Using wavelet toolbox in matlab The DWT of the stator current was obtained using the wavelet toolbox in MATLAB. Daubechies-44 mother wavelet was used for analysis of the current signal fig shows the primary current of the stator associated with the 8-level DWT of the startup current of a healthy motor under load. It can be clearly observed that the upper level signal A8 (approximation), D8 and D7 (details) do not show any considerable deviation apart from the initial oscillations lasting only for a few cycles. From this, it can be concluded that the harmonic associated with broken bars is not present in this condition. Using wavemenu toolbox in MATLAB we can do wavelet analysis of stator current, here one dimensional wavelet analysis is done on stator current using Daubechies-44 mother wavelet having decomposition level of 8. The idea is to choose such a sampling frequency such that 50 Hz component lies in a particular detail signal and thus we can see the upper or lower sideband in a specific detail signal either above or below principal component fig 12 displays the DWT analysis of the current of a loaded motor with six broken rotor bars. As shown in figure, a significant increase with respect to the healthy state appears in the energy of the upper level signals D8 and D7 (details). The oscillations in those signals are due to the evolution of the f_{lsb} (lower side band) component during the transient. These oscillations follow a sequence that is according to the frequency evolution of the f_{lsb} on FFT based fault detection technique.

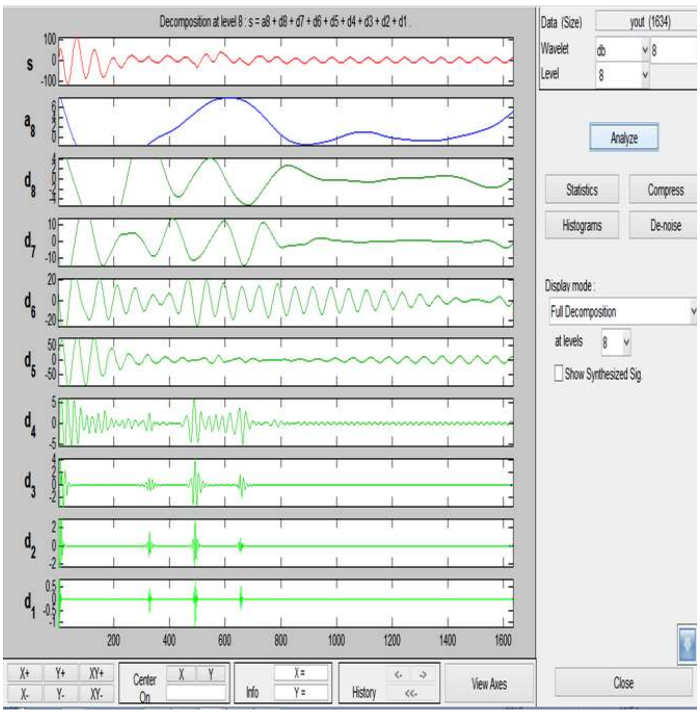

Fig 11 Wavelet healthy signal

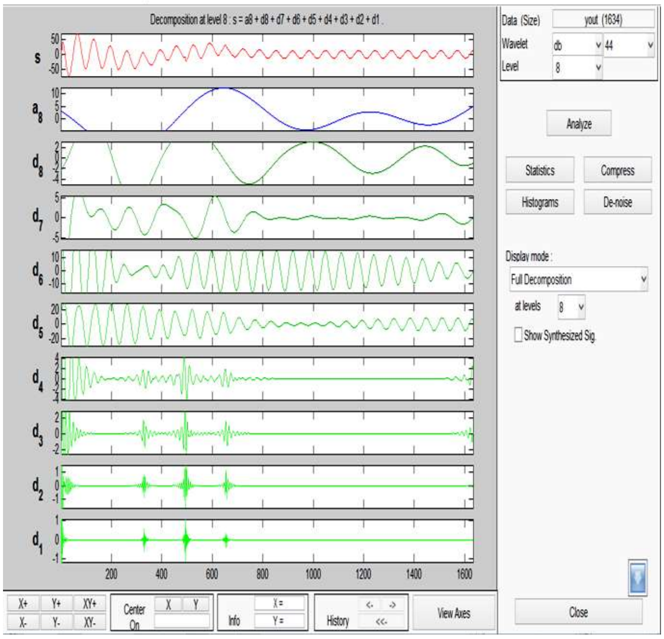

Fig 12 Wavelet for faulty motor 6 broken bar

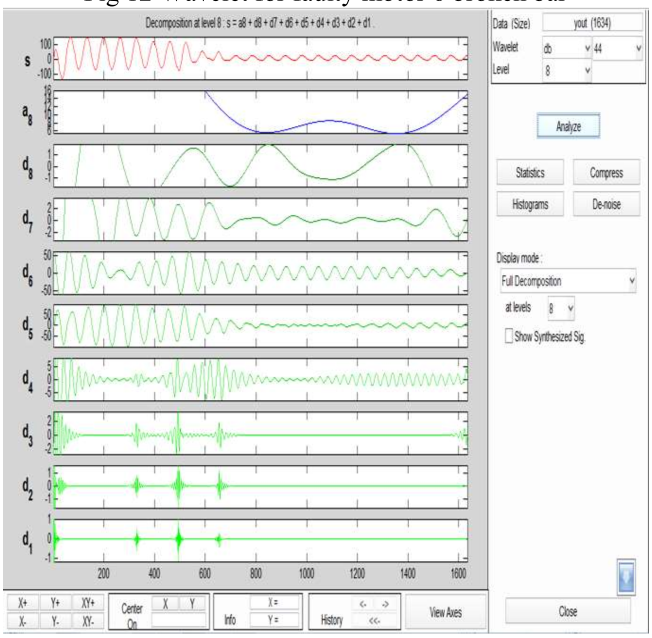

Fig 13 Stator winding fault

V. Conclusion

Wavelets since 1980's has been one of the most dominant equipments of data analysis, that's why it also considered for fault detection in induction motors as well .This case study presents a broken rotor bar analysis as well as stator winding short circuit using wavelets and concepts of fault detection using wavelets .A significant change in energy of approximate and details signal indicates a presence in fault which can be localized in time. Wavelets are important in fault analysis especially in case of non stationary signals. Different varieties of mother wavelet functions are a key strength in wavelet analysis, and proper selection of mother wavelets is a vivid area of research. The WT and FFT method together gives a complete condition monitoring system which works in stationary as well as in non stationary conditions which is the practical requirement of the industry. In case of FFT load must be present for detection of fault [7] while in case of wavelets this is not the case as using wavelets small discontinuities can be detected by decomposing the signals into approximate and detail signals. WT analysis can also be successfully implemented for varying load as well as it gives the exact time of occurrence of faults.

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